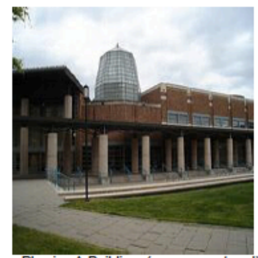
George and Neutron-Proton Pairing

Augusto O. Macchiavelli

Nuclear Science Division
Lawrence Berkeley National Laboratory



Physics A Building (across courtyard)

THE GEORGE BERTSCH SYMPOSIUM

September 7-9th, 2012
University of Washington - Seattle

BERKELEY LAB
Lawrence Berkeley National Laboratory

U.S. DEPARTMENT OF ENERGY | Office of Science

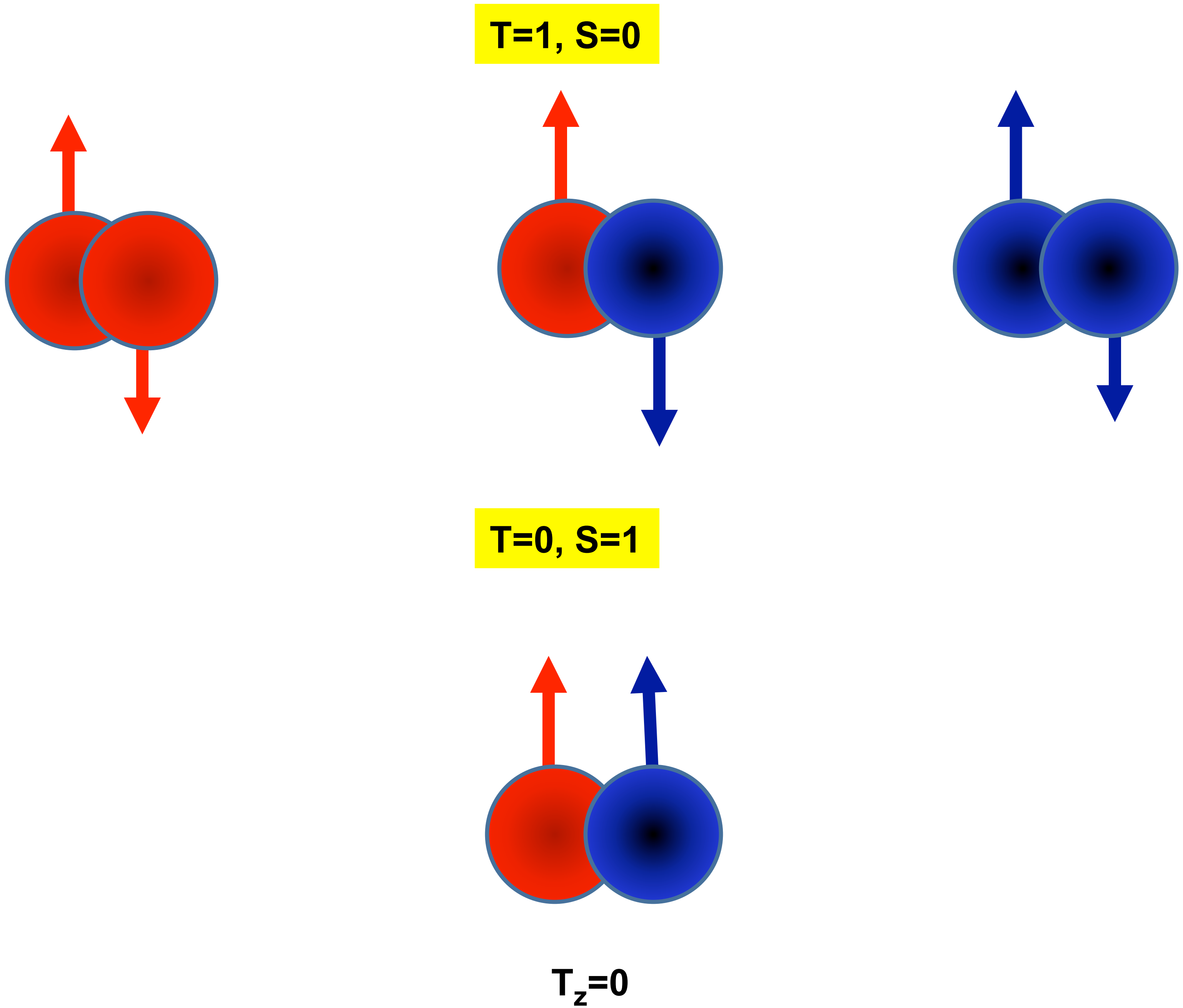
Work supported under contract number DE-AC02-05CH11231.

George F. Bertsch / THE PRACTITIONER'S SHELL MODEL

North-Holland / American Elsevier

Probing Neutron-Proton Pair Correlations

19-20 November 2010 | Nishina Memorial Building, RIKEN Wako-campus


T=1, S=0
T=0, S=1
T_z=0

T=1, S=0

T=0, S=1

T_z=0

N=Z nuclei, unique systems to study *np* correlations

As you move out of N=Z *nn* and *pp* pairs are favored

Role of isoscalar (T=0) and isovector (T=1) pairing

Large spatial overlap of *n* and *p*

Pairing vibrations (normal system)

Pairing rotations (superfluid system)

Does isoscalar pairing give rise to collective modes?

Possible Signals

BE differences can be described by an appropriate combination of the symmetry energy and the isovector pairing energy. Evidence for full isovector pairing (nn,np,pp) - charge independence.

Isovector Pairing-Vibrations around ^{40}Ca and ^{56}Ni

Odd-odd low lying states: quasi-deuteron structure.
Lisetskiy, Jolos, Pietralla, von Brentano

Rotational properties ("delayed alignments") consistent with T=1 cranking model.
Fischer, Lister - Afanasjev, Frauendorf

Beta Decay: Strong N=Z-2 ➔ N=Z - 0^+ ➔ 1^+ transition.
Gadea, Algora, et al.

Spin-aligned neutron-proton coupling scheme in ^{92}Pd
Bo Cederwall et al. , Nature , Piet Van Isacker

Proc. Int. Symp. On Nuclear Structure, IAEA –

2.G

Nuclear Ph

Not to be rep

NOTE ON TH

)NS

Radiation Lab

Abstract: The magnitud
interaction model. T
types of reaction a co

PHYSICS REPORTS (Section C

:TIONS

State University of Ne

The Niels Boh
State University of N

*lifornia**

Los Alamos, New Mexico 87544

and

Claus Riedel

and

Ole HANSEN and O. NATHAN

The Niels Bohr Institute, University of C

ndorf, D.D.R.

Could this be the smoking gun?

Marx Stadt

Volume 37B, number 4 PHYSICS LETTERS 13 December 197

ENHANCEMENT OF DEUTERON TRANSFER REACTIONS BY NEUTRON-PROTON PAIRING CORRELATIONS*

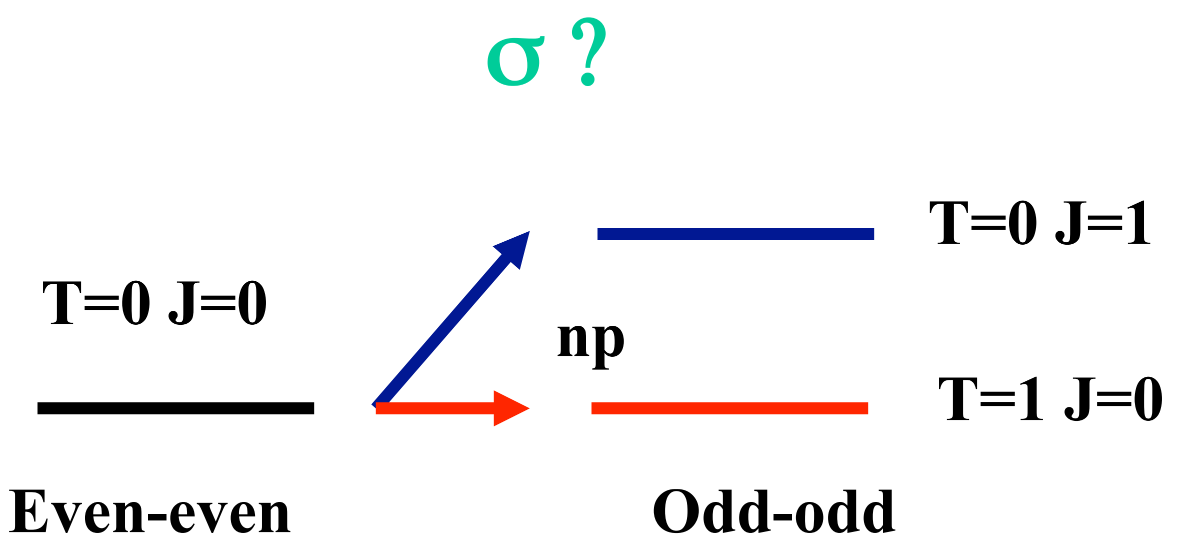
P. FRÖBRICH
Physik-Department der Technischen Universität München,
Teilinstitut Theorie, München, Germany

Received 7 October 1971

It is shown for ^{36}Ar (p, ^{3}He)^{34}Cl that the transfer of a neutron-proton pair is enhanced as compared to the shell model if one takes into account $T = 0$ and $T = 1$ neutron-proton pairing correlations in the description of target and residual nucleus.

$$d\sigma / d\Omega \approx 2.5 d\sigma / d\Omega_{sp}$$

(^{3}He,p) Transfer Reactions

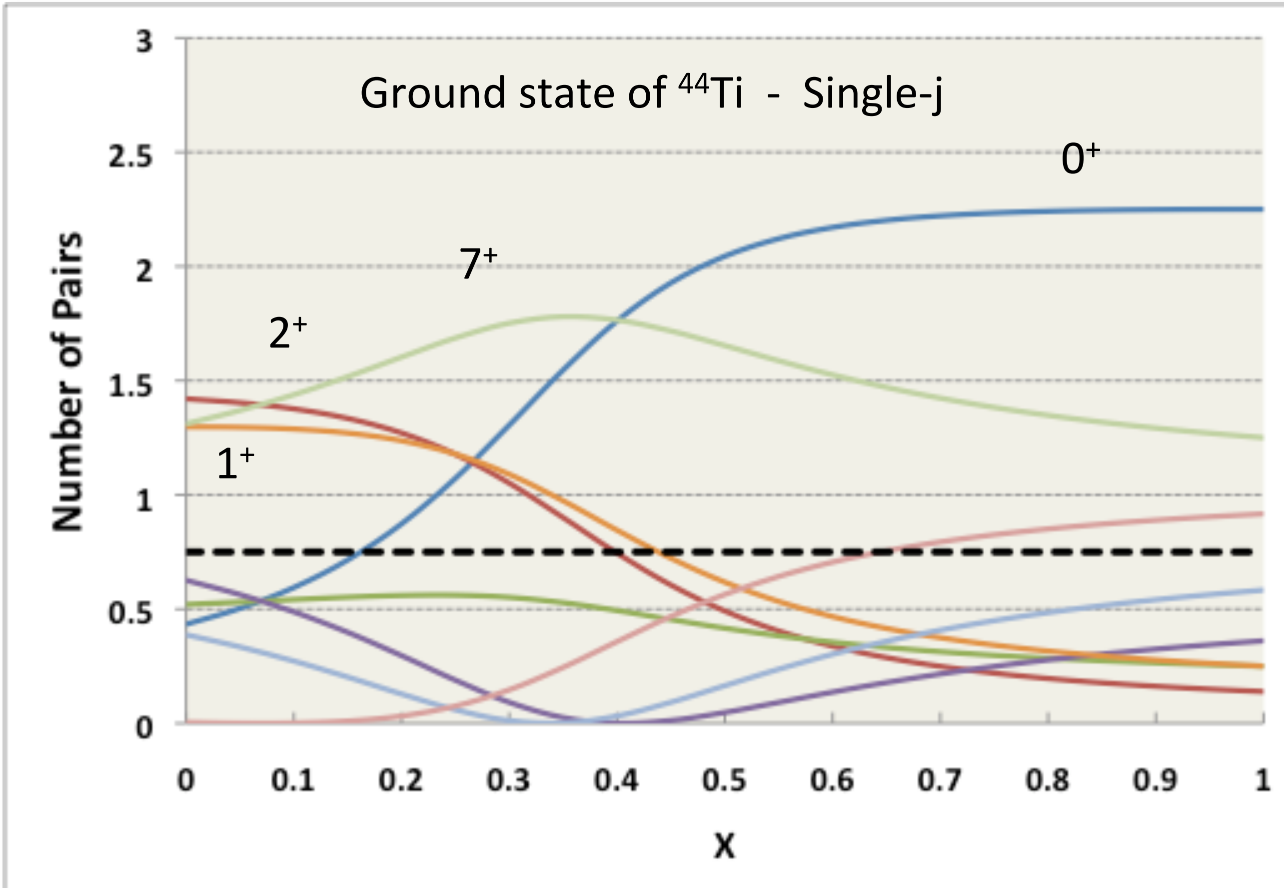


(^{3}He,p) - L=0 transfer

Measure the *np* transfer cross section to T=1 and T=0 states

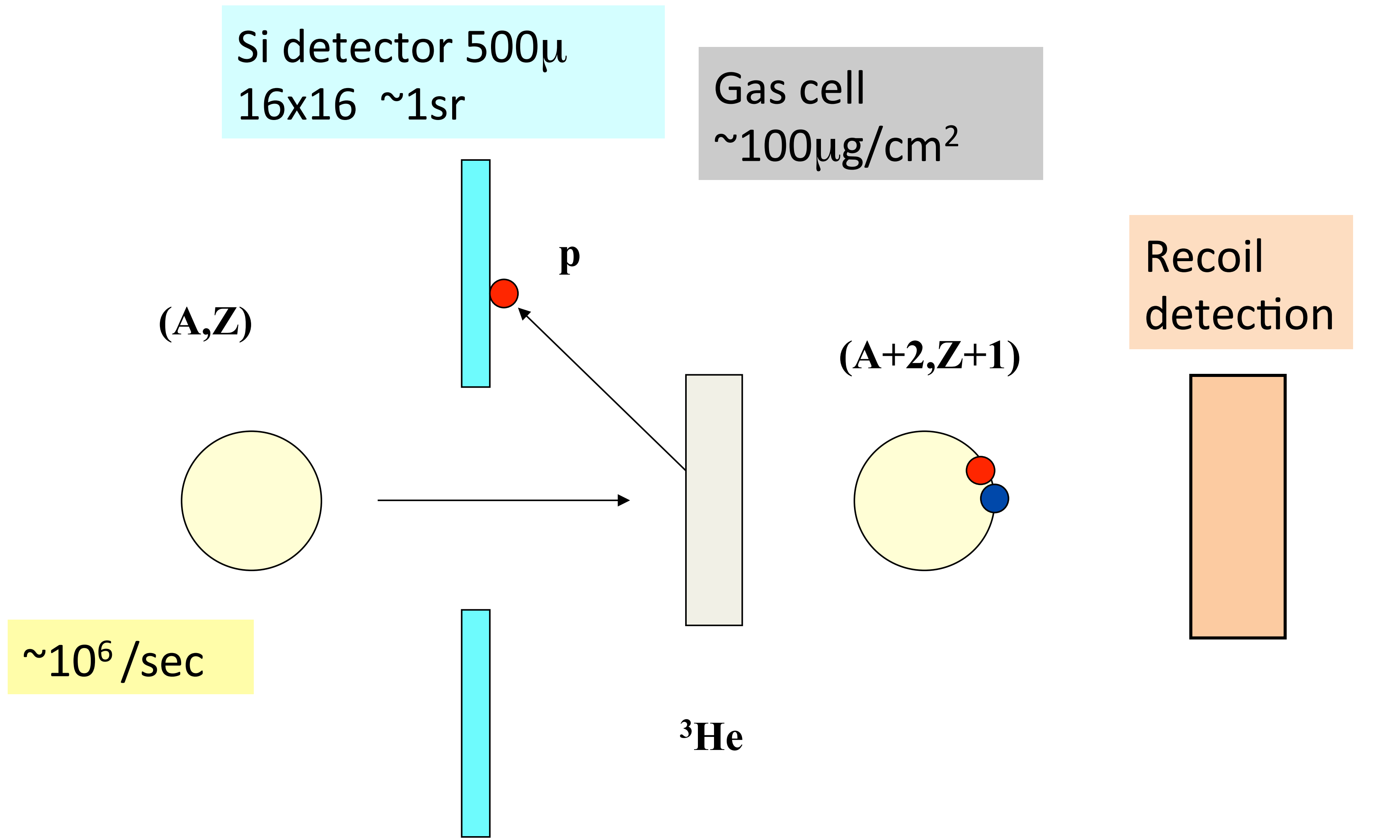
Both absolute σ(T=0) and σ(T=1) <u>and</u> relative σ(T=0) / σ(T=1) tell us about the character and strength of the correlations

$$V_{JT} = x\,\delta_{T=1,J=0} + (1-x)\,\delta_{T=0,J=1}$$



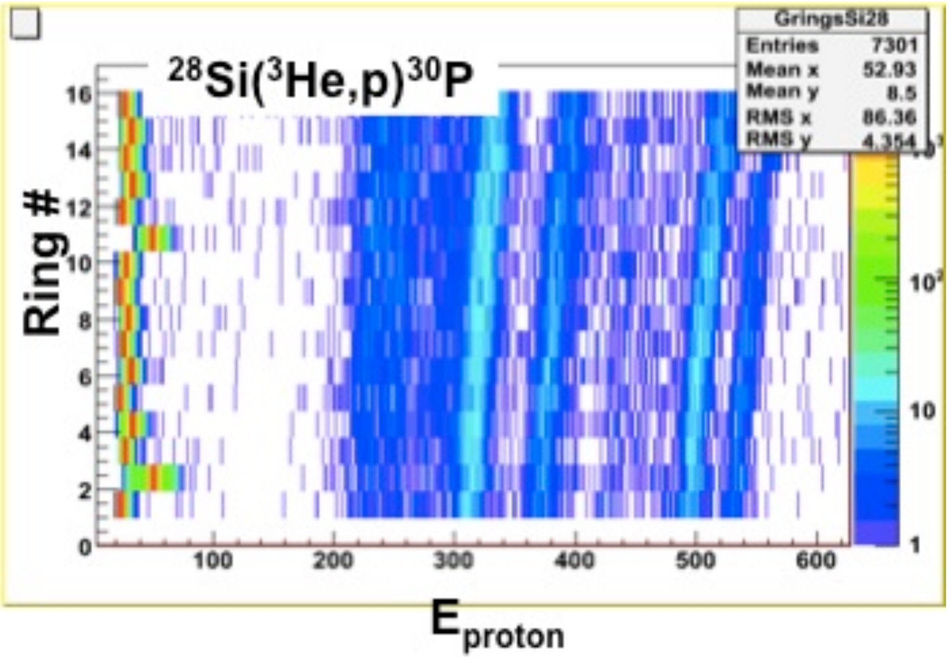
Isoscalar Isovector

L.Zamick et al. Phys.Rev C71 034317(2005)

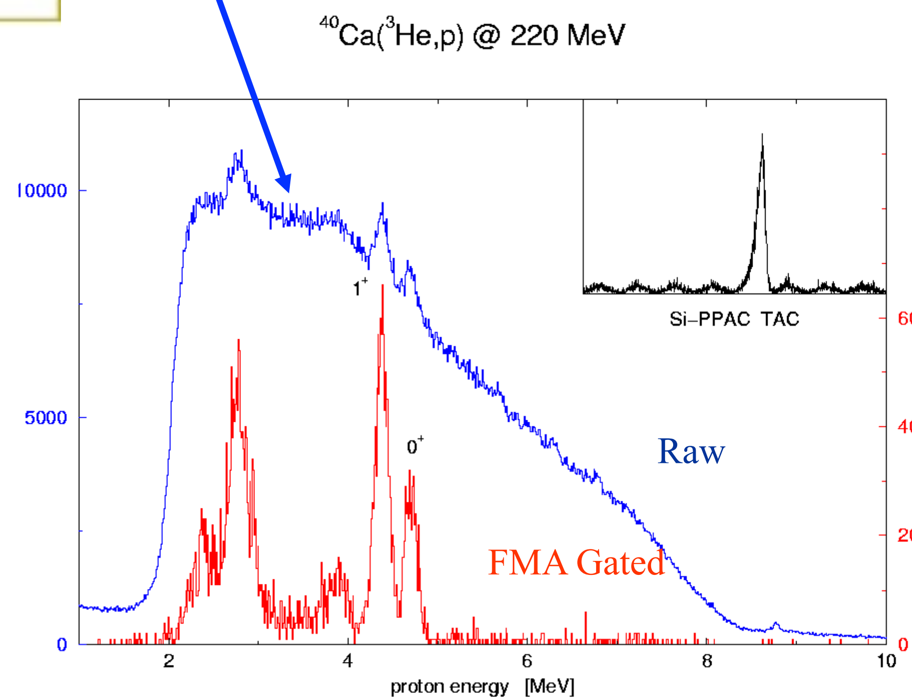


Measure E(Θ), dσ/dΩ (Θ), σ

~ 20 counts/day

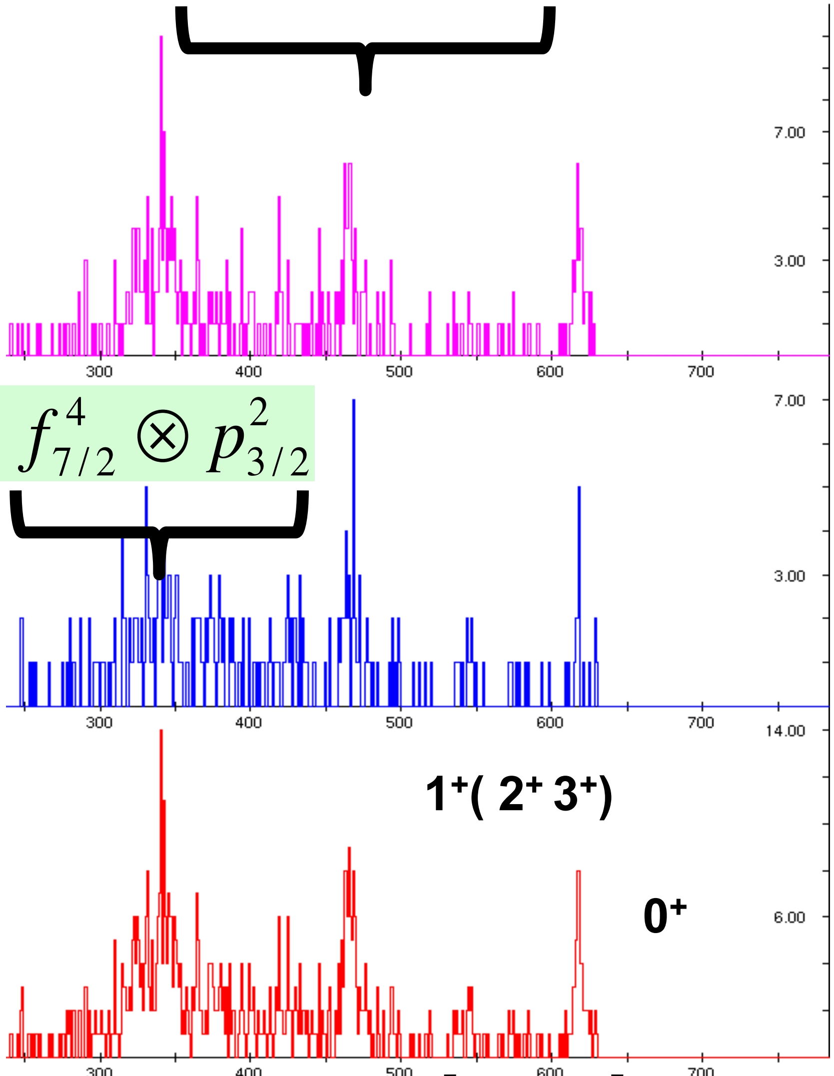


Evaporation protons



A=46 ^{44}Ti (^{3}He,p) → ^{46}V

$$L = 2 - f_{7/2}^{5} \otimes p_{3/2}^{1}$$



rings 8-15
theta ~155-163

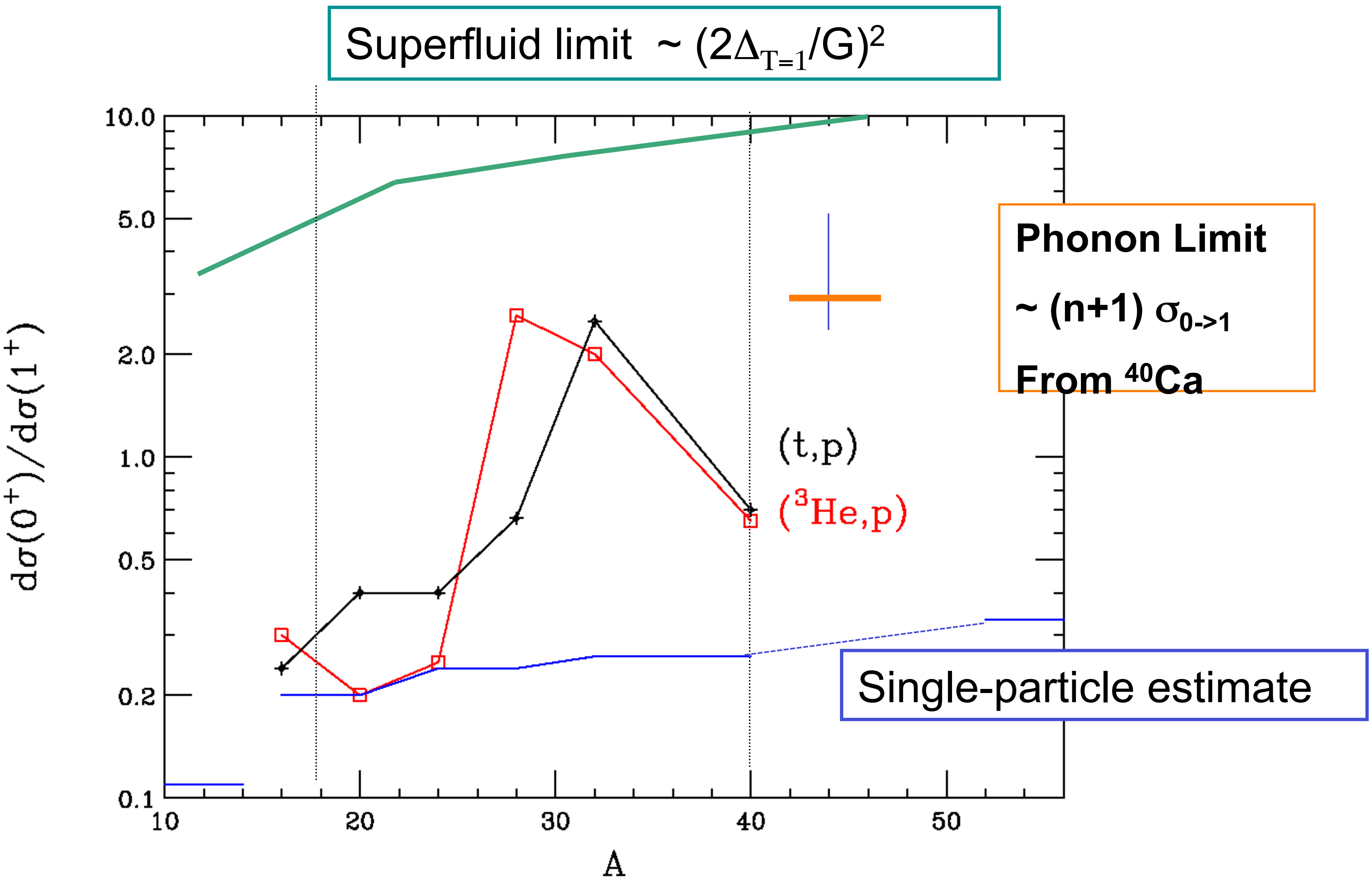
$$L = 0 - f_{7/2}^{4} \otimes p_{3/2}^{2}$$

rings 0-7
theta ~148-155

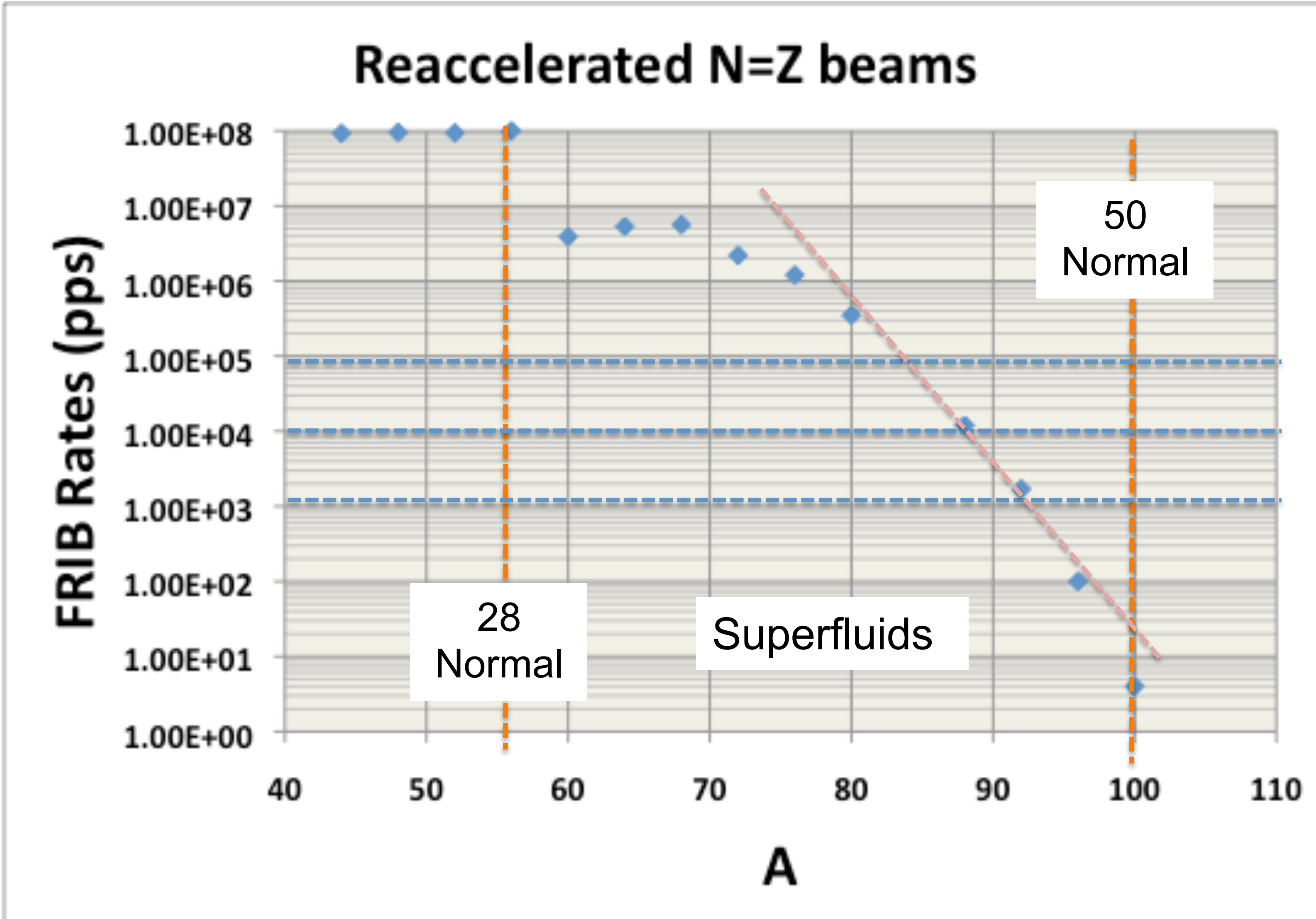
total

$$L = 0 - f_{7/2}^{6}$$

Systematic of (^{3}He,p) and (t,p) reactions in stable N=Z nuclei



Jenny Lee *et al.* RCNP program



Simple
Setup

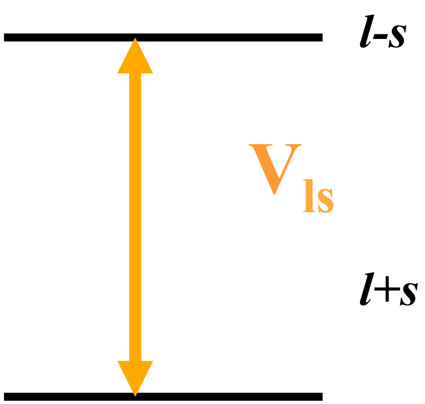
HELIOS

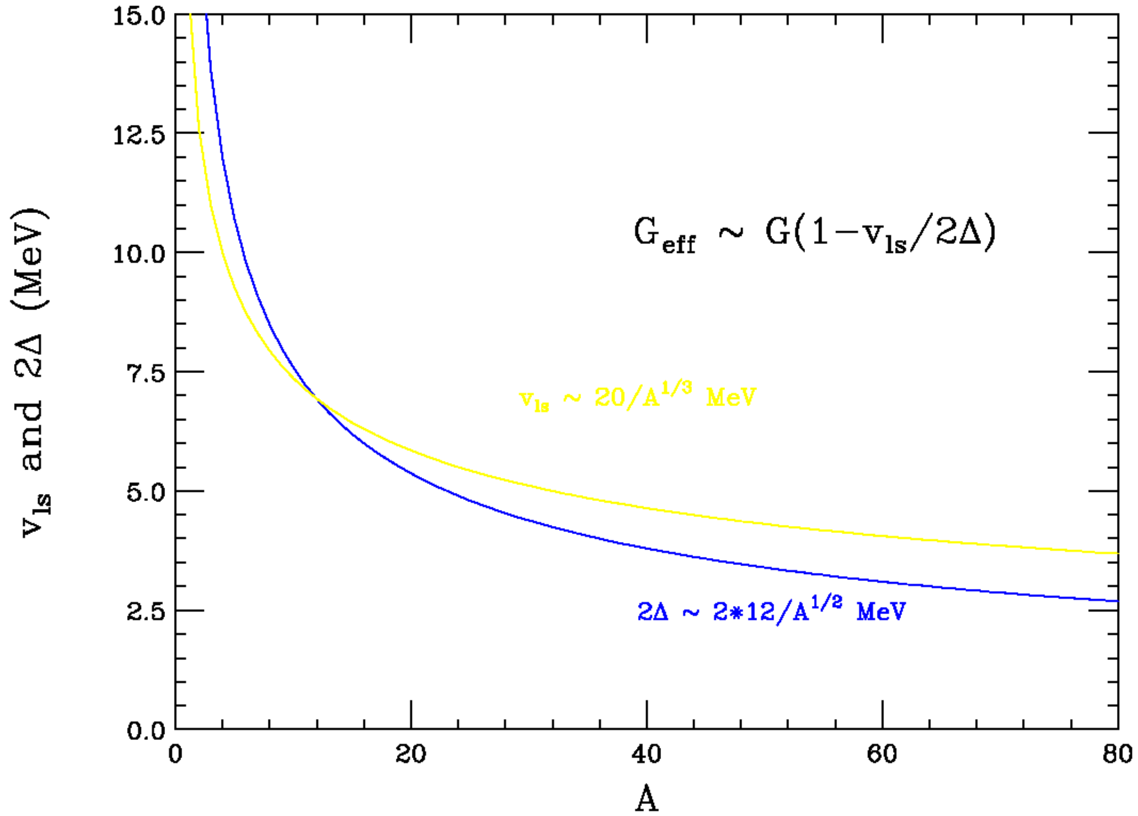
AT-TPC

Although simple arguments may suggest that isoscalar pairing should be important, it is still not clear if it gives rise to collective modes.

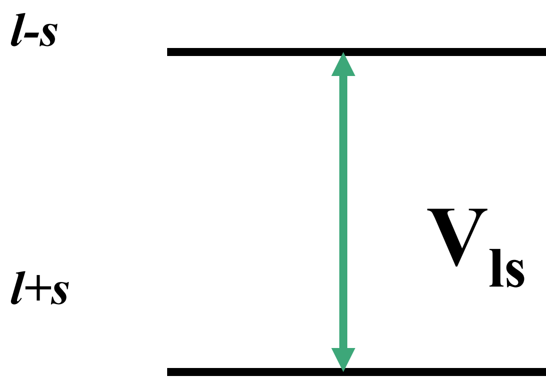
Why?

Spin-Orbit Splitting





Single-j shell model



L=0 matrix elements

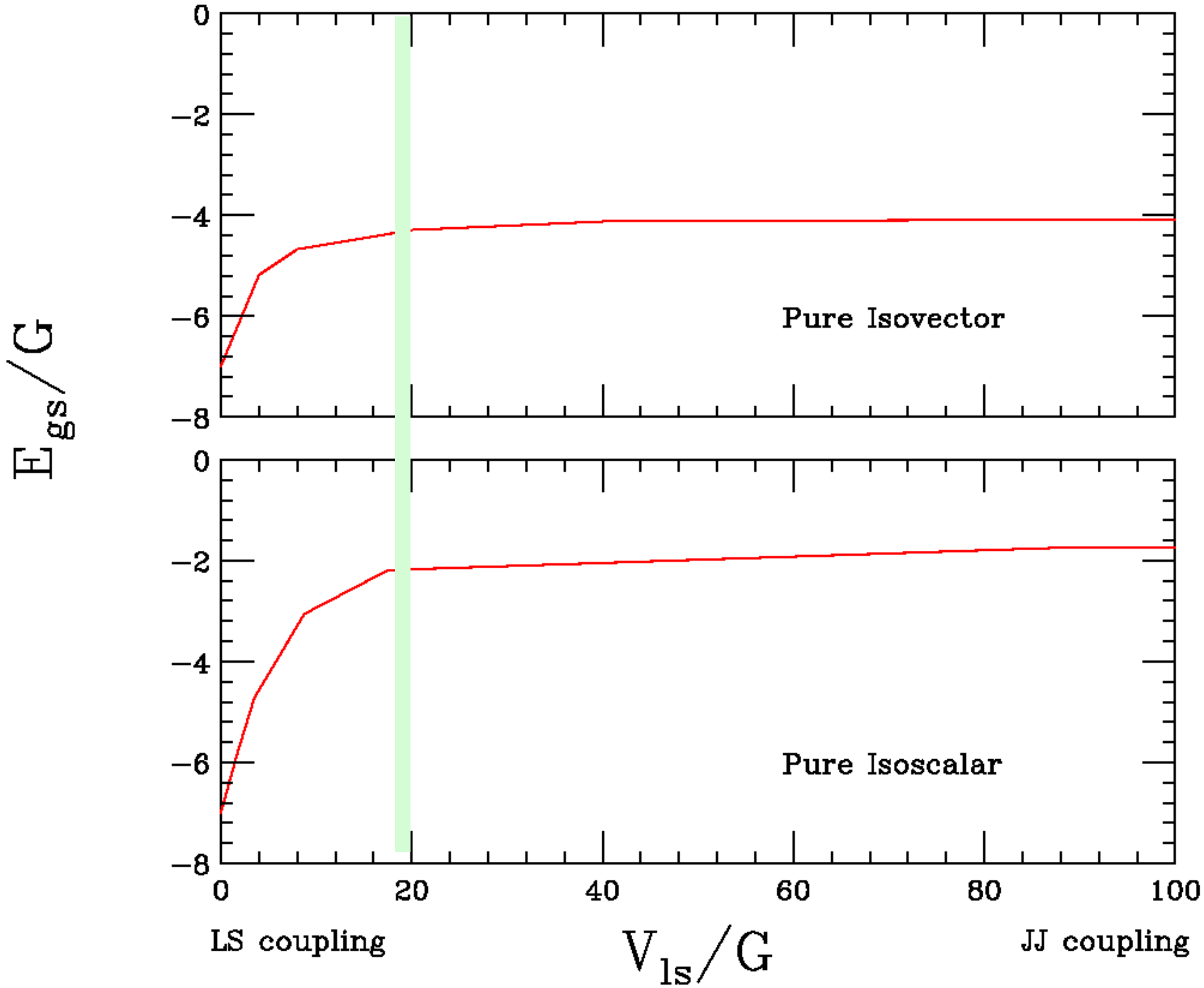
$$V_{ls} \to 0 \quad \text{l-shell}$$

$$V_{ls} \to \infty \quad \text{j-shell}$$

$$\boxed{V = x\, V_{T=1,J=0} + (1-x)\, V_{T=0,J=1}}$$

OXBASH B.A.Brown *et al*., MSU Report **524** (1998)

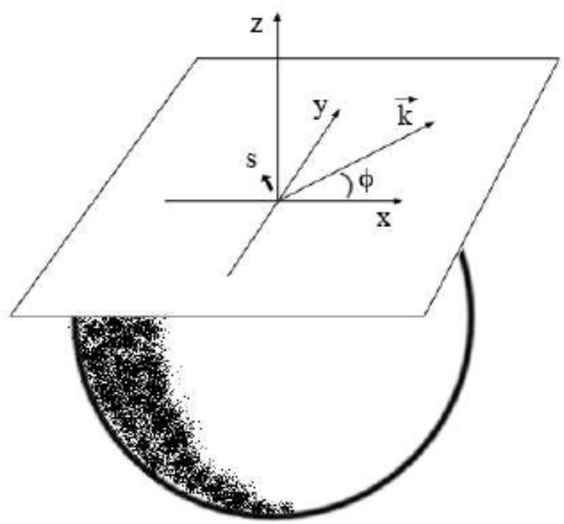
Two particles



Suppression of isoscalar pairing

G.F. Bertsch and Simone Baroni
Department of Physics and Institute for Nuclear Theory, University of Washington, Seattle, WA 98195

The short-range nuclear attraction is stronger in the isoscalar channel than in the isovector channel, as evidenced by the existence of the deuteron and not the dineutron. Nevertheless, apart from light $N = Z$ nuclei, pairing is only seen in the isovector channel. This is explained by the effect of the strong spin-orbit splitting on the single-particle energies. A semiquantitative argument is presented treating the high-j orbitals at the Fermi surface as plane waves on a two-dimensional sheet.



PHYSICAL REVIEW C **81**, 064308 (2010)

Partial-wave contributions to pairing in nuclei

Simone Baroni,[1,2,*] Augusto O. Macchiavelli,[3,†] and Achim Schwenk[2,4,5,‡]

PHYSICAL REVIEW VOLUME 73, N

Letters to the Editor

PUBLICATION of brief reports of important discoveries in physics may be secured by addressing them to this department. The closing date for this department is five weeks prior to the date of issue. No proof will be sent to the authors. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents. Communications should not exceed 600 words in length.

The Origin of Chemical Elements

R. A. ALPHER*
Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Maryland
AND
H. BETHE
Cornell University, Ithaca, New York
AND
G. GAMOW
The George Washington University, Washington, D. C.
February 18, 1948

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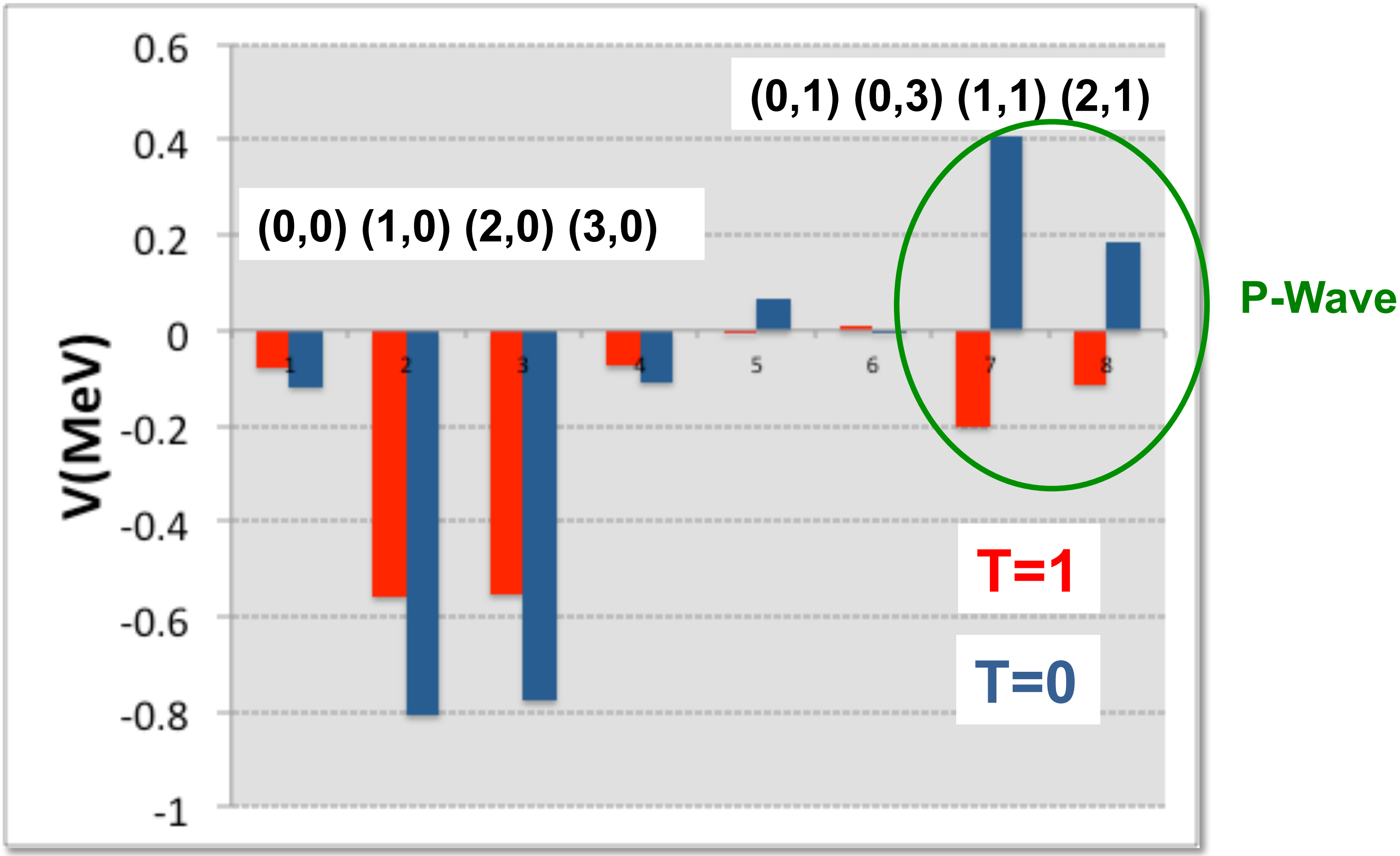
(N, Λ , **<u>n, λ</u>**)

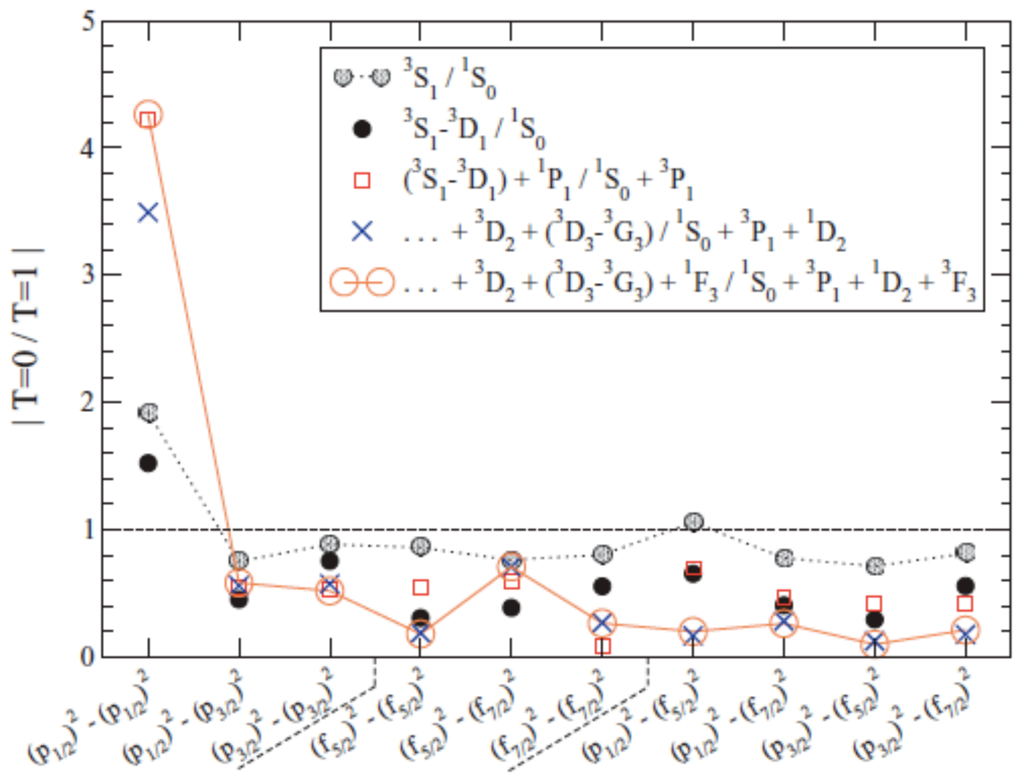


$f_{7/2}$ Schiffer-True interaction oscillator parameter = 0.26 fm^{-1}

PHYSICAL REVIEW C **81**, 064308 (2010)

Partial-wave contributions to pairing in nuclei

Simone Baroni,[1,2,*] Augusto O. Macchiavelli,[3,†] and Achim Schwenk[2,4,5,‡]



PHYSICAL REVIEW C **81**, 064320 (2010)

Spin-triplet pairing in large nuclei

G. F. Bertsch and Y. Luo
Institute for Nuclear Theory and Department of Physics, University of Washington, Seattle, Washington, USA
(Received 4 January 2010; published 23 June 2010)

Hartree-Fock-Bogoliubov Equations

$$\hat{H} = \sum_i \langle i|H_{\rm sp}|j\rangle a_i^\dagger a_j + \sum_{i>j,k>l} \langle ij|v|kl\rangle a_i^\dagger a_j^\dagger a_l a_k.$$

$$H_{\rm sp} = \frac{p^2}{2m} + V_{\rm WS}\, f(r) + \vec{\ell}\cdot\vec{s}\, V_{\rm so}\frac{1}{r}\frac{df(r)}{dr}$$

TABLE I. Strengths of triplet and singlet interactions from shell-model fits and their ratios. See text for details.

Source	v_s (MeV fm^3)	v_t (MeV fm^3)	Ratio
sd shell [8]	280	465	1.65
fp shell [9]	291	475	1.63

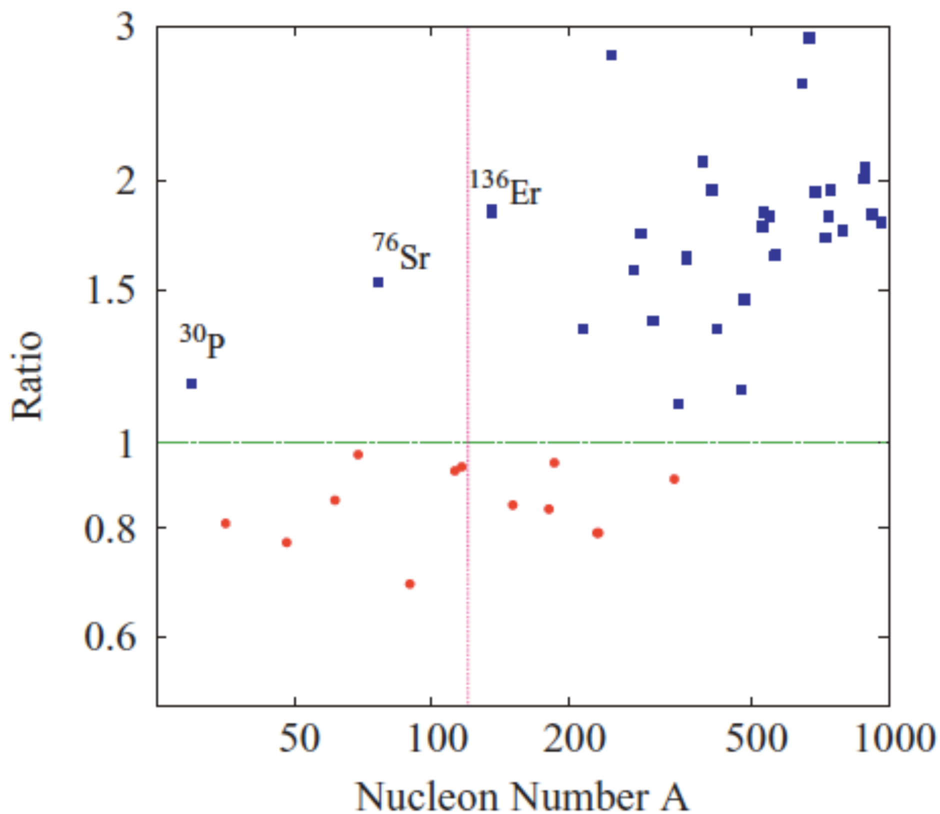


FIG. 2. (Color online) Ratio of spin-triplet to spin-singlet correlation energies as a function of mass number A. Nuclei with spin-singlet and spin-triplet condensates are shown as red circles and blue squares, respectively. The vertical line at $A \approx 120$ shows the dividing line between nuclei that are bound (left) and nuclei that are unstable with respect to proton emission, according to the mass table of Ref. [12].

106, 252502 (2011) PHYSICAL REVIEW LETTERS week ending 24 JUNE 2011

Mixed-Spin Pairing Condensates in Heavy Nuclei

Alexandros Gezerlis,[1] G. F. Bertsch,[1,2] and Y. L. Luo[1]
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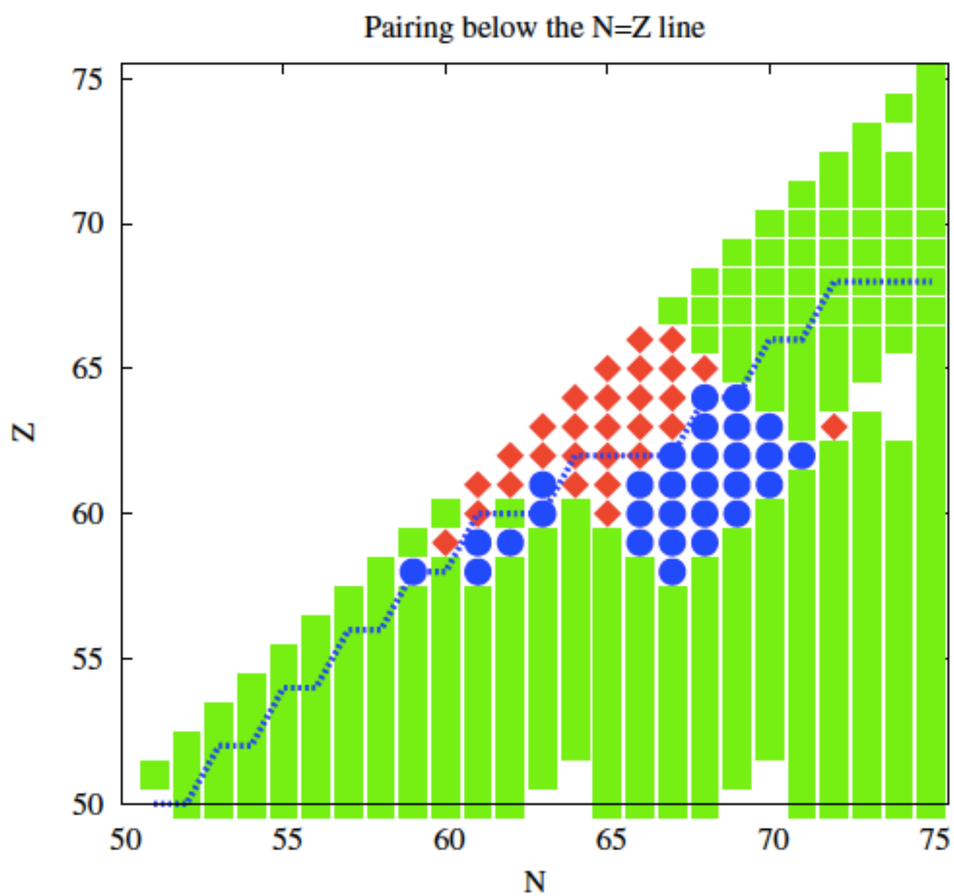
(Received 31 March 2011; published 23 June 2011)



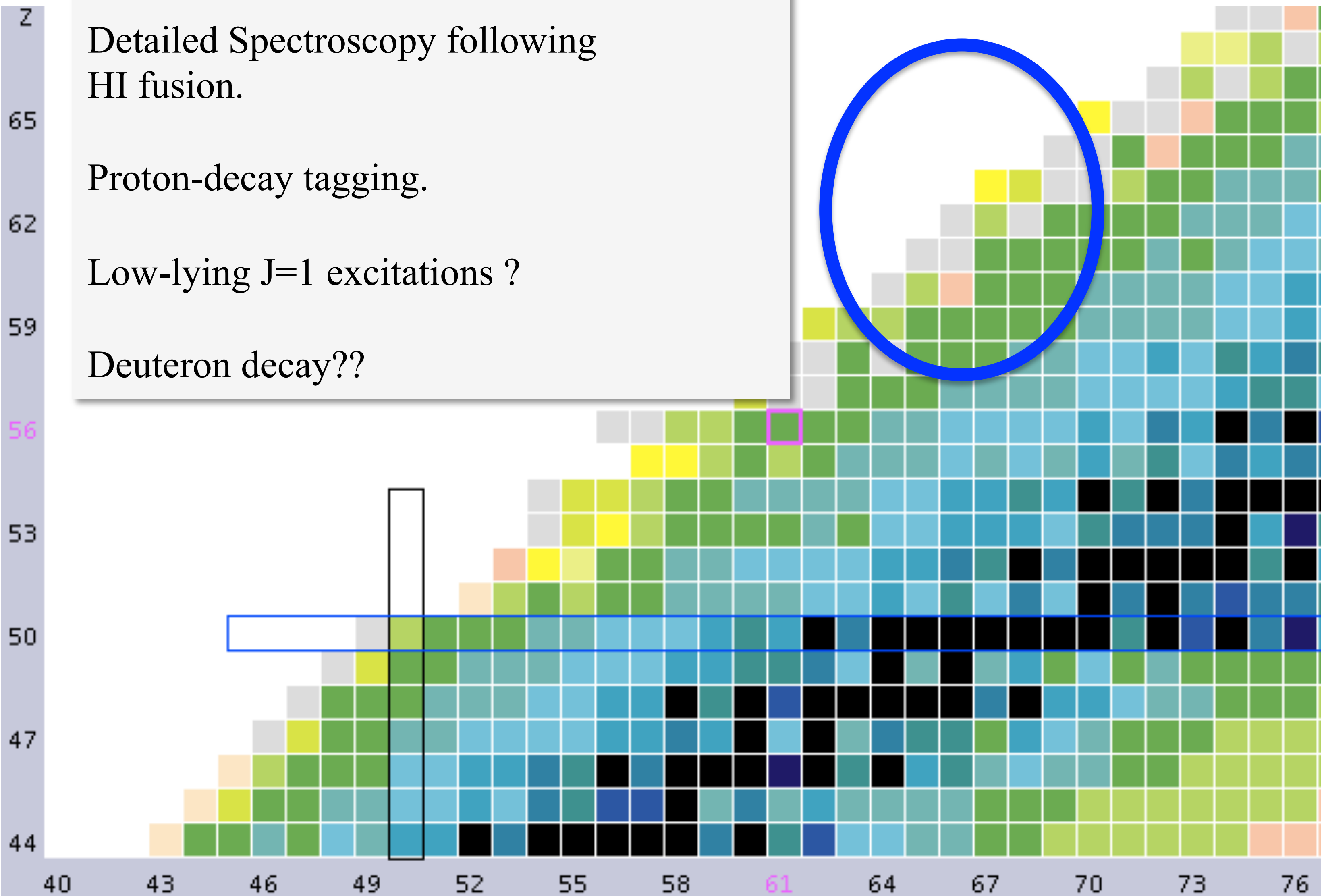
Transfer reactions not likely.

Detailed Spectroscopy following
HI fusion.

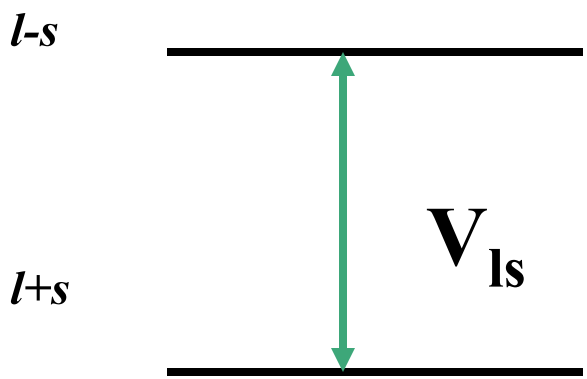
Proton-decay tagging.

Low-lying J=1 excitations ?

Deuteron decay??



Single-*j* shell model



L=0 matrix elements

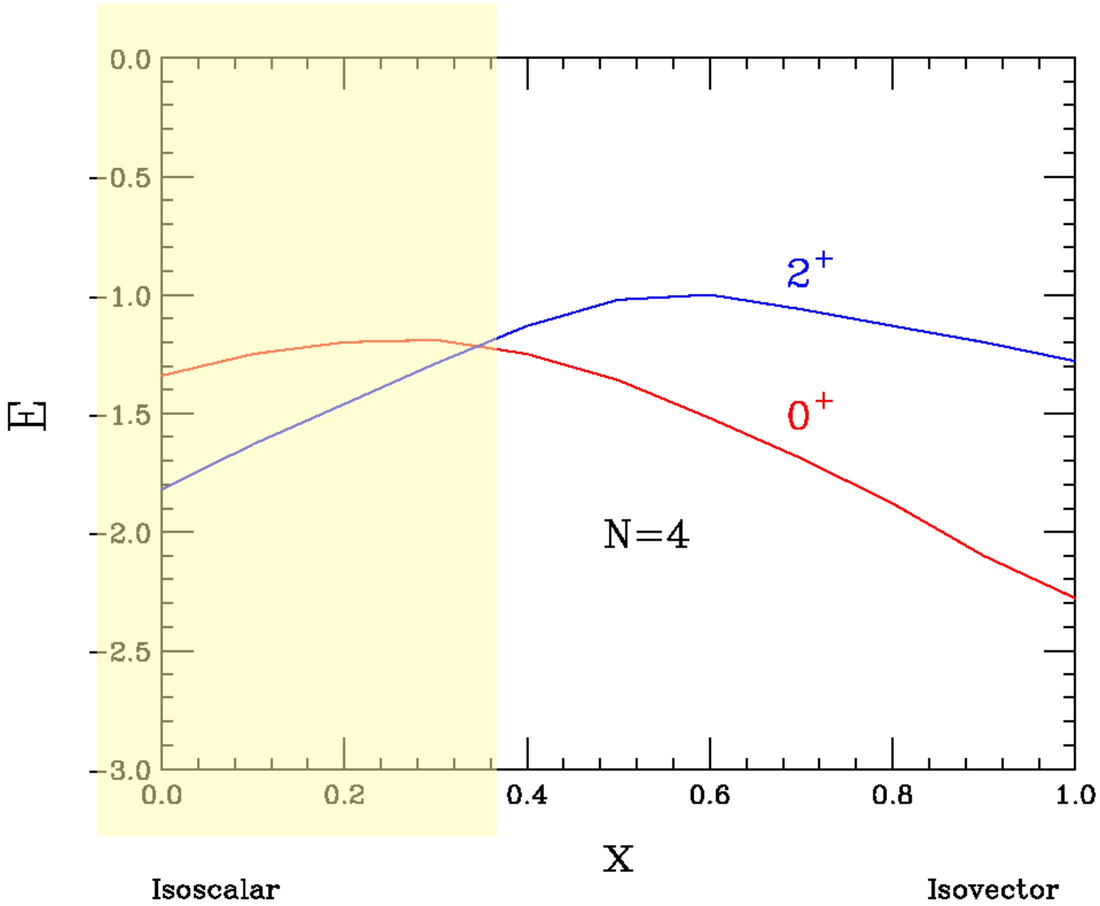
$V_{ls} \rightarrow 0$ **l-shell**

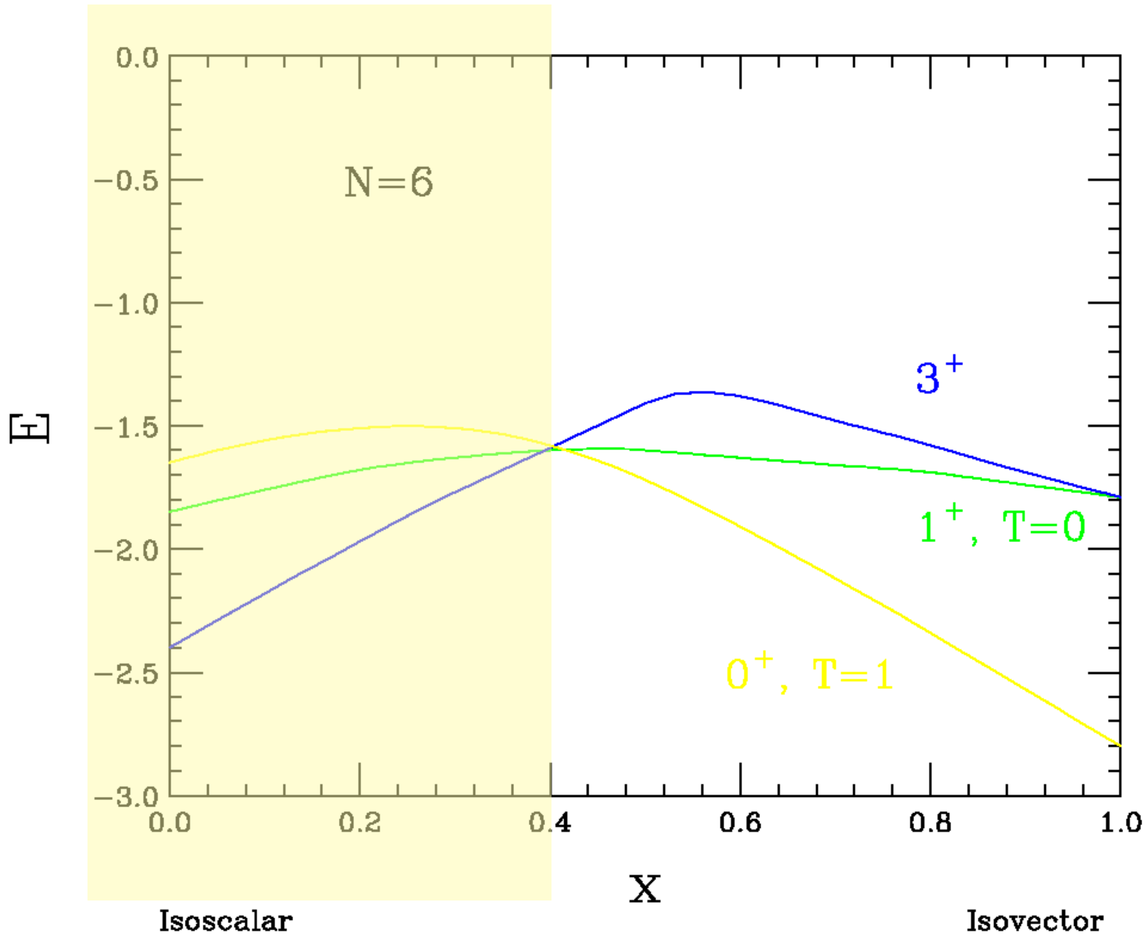
$V_{ls} \rightarrow \infty$ **j-shell**

$$V = x\, V_{T=1,J=0} + (1-x)\, V_{T=0,J=1}$$

OXBASH B.A.Brown *et al*., MSU Report **524** (1998)

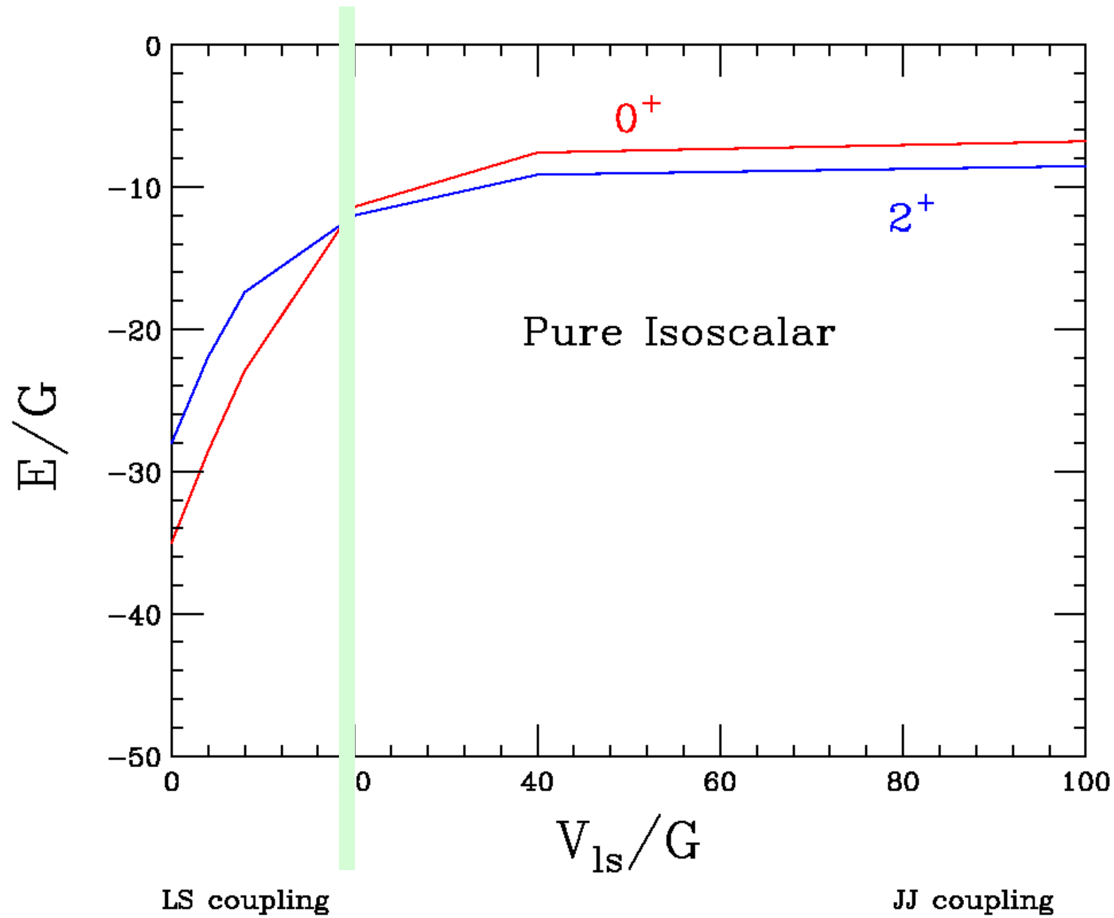
… and more interesting





Ground state has aligned spins!!!

This happens as the JJ coupling sets in



Not the case in nuclei, but

can it be tested in mixed fermion traps?

N=2n particles with pure Isoscalar interaction g_{10} in a single j-shell

Boson Mapping

$$\hat{H}_{\mathrm{b}} = \epsilon_p p^\dagger \cdot \tilde{p} + \frac{1}{2} \sum_{\lambda=0,2} \nu_\lambda [p^\dagger \times p^\dagger]^{(\lambda)} \cdot [\tilde{p} \times \tilde{p}]^{(\lambda)},$$

$$\begin{aligned}
E(p^n, J=0) &= n\epsilon_p + \frac{n(n+1)}{6}\nu_0 + \frac{n(n-2)}{3}\nu_2, \qquad n \quad \text{even},\\
E(p^n, J=1) &= n\epsilon_p + \frac{(n-1)(n+2)}{6}\nu_0 + \frac{(n-1)^2}{3}\nu_2, \qquad n \quad \text{odd},\\
E(p^n, J=n) &= n\epsilon_p + \frac{n(n-1)}{2}\nu_2,
\end{aligned}$$

$$\begin{aligned}
\nu_0 &= \frac{-6(j^2+j-1)}{j(j+1)(2j+1)} g_{10} \stackrel{j\to\infty}{\longrightarrow} \left[-\frac{3}{j} + \mathcal{O}\left(\frac{1}{j^2}\right)\right] g_{10},\\
\nu_2 &= \frac{-3(4j^4+6j^3+j^2+7j+12)}{j(j+1)(2j+1)(5j^2+7j+3)} g_{10} \stackrel{j\to\infty}{\longrightarrow} \left[-\frac{6}{5j} + \mathcal{O}\left(\frac{1}{j^2}\right)\right] g_{10}.
\end{aligned}$$

Collaboration with Piet Van Isacker

APS physics Weekly NewsBrief
A WEEKLY NEWS AND INFORMATION RESOURCE FROM THE AMERICAN PHYSICAL SOCIETY

Ultracold fermions simulate spin-orbit coupling

Physics World Share

Two independent groups of physicists are the first to use ultracold fermionic atoms to simulate "spin-orbit coupling" - an interaction that plays an important role in the electronic properties of solid materials. Both experiments were done by firing laser beams at the atoms, which caused their momentum to change by an amount that depends on their intrinsic spin. Read the associated Physics Viewpoint. **MORE**

Summary

Although simple arguments may suggest that isoscalar pairing should be important, it is still not clear if it gives rise to collective modes.

Spin-orbit

J=1 pairs   P-wave contribution to matrix-elements

Core polarization

George's deep insight has shed light in our understanding of the *n-p* pairing.

Detailed spectroscopy near the proton drip line at Z ~ 60

J=1 pair excitations.

(p,^{3}He) and (^{3}He,p) are the *"classical"* probes we can use to firmly elucidate this question, particularly in the region from ^{56}Ni to ^{100}Sn

Radioactive beams require inverse kinematics:

Proof of principle with stable beams

Successful first experiment with a ^{44}Ti beam

NP Knockout reactions ?

George

On your 70th B-Day and your remarkable contributions to physics !!